	Maximum.	Minimum.
Length of humerus	0·19	0·17
„ radius	0·215	0·175
„ metacarpus	0·19	0·16
„ femur	0·215	0·21
„ tibia	0·26	0·22
„ metatarsus.........	0·203	0·18
„ calcaneum	0·095	0·063
„ astragalus	0·04	0·035

The small dimensions of all these Cervine remains suggest a comparison at first with the common Fallow Deer (*Cervus dama*); and it is quite possible that some specimens—notably those from Excavation No. IV—may represent this southern European form, which has already been recognised by Busk in the caverns of Gibraltar. The limb bones, however, appear to the present writer to be slightly more robust than those of the Fallow Deer of corresponding size; and the antlers conclusively prove that most of the remains, at any rate, do not belong to this species. The antlers may be assigned with certainty to the small variety of *Cervus elaphus* which now lives in Northern Africa, and is known as the Barbary Deer (*Cervus barbarus* of Gray); the Maltese fossils, however, indicate an animal of smaller dimensions than its existing representative and its contemporaneous ally discovered in the caverns of Gibraltar.

"The Effects of Mechanical Stress on the Electrical Resistance of Metals." By JAMES H. GRAY, M.A., B.Sc., and JAMES B. HENDERSON, B.Sc., "1851 Exhibition" Science Scholars, Glasgow University. Communicated by LORD KELVIN, P.R.S. Received February 10,—Read March 2, 1893.

This investigation was begun under the instructions of Lord Kelvin about a year ago, and has been continued since the beginning of last year in conjunction with another on thermal conductivity, for which a grant of £50 was made from the Government Research Fund.

The chief object of the investigation was to obtain quantitative results of the variations of specific resistances of metals due to stretching, twisting, drawing through holes in a steel plate, hammering, heating, and combinations of these, while in some of these cases the alteration of density was also measured.

The most exhaustive results that have been hitherto given in this direction are those of Lord Kelvin, published in vol. 2 of his 'Re-

print of Mathematical and Physical Papers'; of Dr. A. Matthiessen, F.R.S., published in the 'British Association Reports' for 1862, 1863, 1864, and 1865; and those of Mr. Herbert Tomlinson, F.R.S., given in several papers communicated to the Royal Society in 1877 and subsequent years. The paper of the last, dealing most particularly with the present investigation, is contained in the 'Phil. Trans.,' 1883, pp. 1—72, "On the Influence of Stress and Strain on the Action of Physical Forces."

As this work was done at two different periods of time, it has been found convenient to divide the paper into two parts. Part I, which contains the results of change of density due to the different kinds of treatment, was done previous to last July. Part II contains the results of alteration of resistance due to stretching, the preliminary work and trial methods, which occupied a very considerable time, having been done in conjunction with the work of Part I.

Part I.

By James H. Gray.

Density.

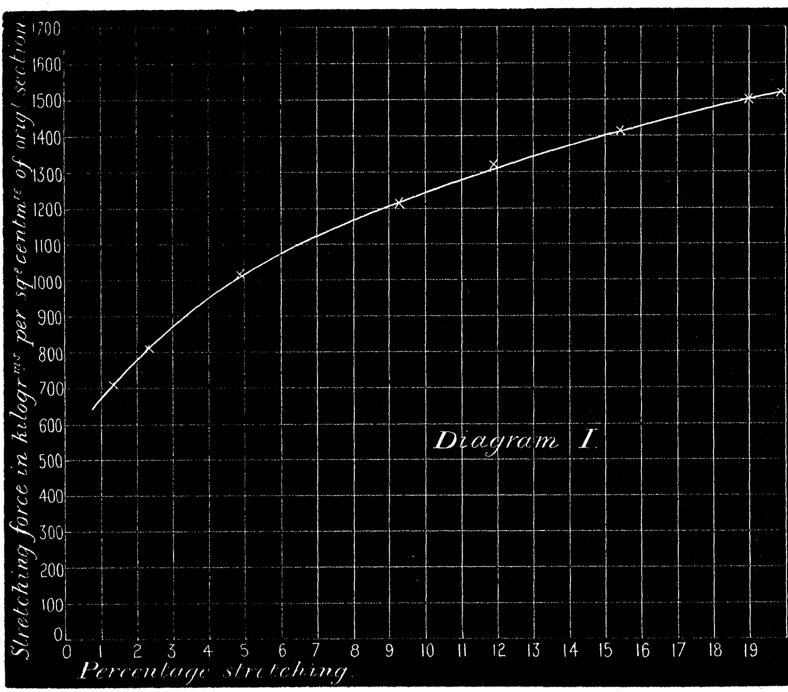
As, in every case, the alterations were expected to be small, great care had to be taken to have all the apparatus as sensitive as possible. A very delicate Oertling balance was used, capable of weighing accurately to within $\frac{1}{10}$ milligramme, and all the usual precautions observed.

Effect of Stretching.

A well-annealed wire of practically pure copper, electrical conductivity 98 per cent., diameter 2 mm., was stretched by weights till it broke. The wire was securely fixed to a strong hook near the ceiling of the laboratory, and two ink marks made, one near the top end, the other near the bottom end. Behind these marks were fixed $\frac{1}{2}$-mm. scales, which enabled the stretching to be recorded. After the wire had been stretched by a weight, a length of about 8 inches was cut off. In this manner successive weights were applied, pieces of the wire being cut off each time, till it broke. Even when so great lengths as 8 inches were taken however, it was found very difficult to weigh very accurately in water, and this, along with possible differences, due to the manner in which the several tests were made, may account for the fact that the intermediate values of the densities varied in different series. The original and final densities of the wire could always be determined very accurately, as much greater lengths of the wire could be used. The numbers below give the values, which were found to be very constant in all the specimens tested.

Original density before stretching = 8·8612
Density after stretching almost to breaking = 8·8187

This shows a decrease in density of fully $\frac{1}{2}$ per cent., and is somewhat greater than what Mr. Tomlinson obtained for the copper which he tested, his result being $\frac{1}{3}$ per cent. In the present tests, the stretching obtained was usually about 25 or 26 per cent. before breaking. Diagram 1 is a stress-strain curve of the copper wire used, the abscissæ denoting percentage strain, the ordinates the stress in kilogrammes per square centimetre of the original section of the wire. This curve is given to show the nature of the wire.



Lead Wire.—A similar series of tests was made on a length of lead wire, diameter 0·8 mm., the stretching being carried on till the wire broke. This point was reached after a stretching of 3·6 per cent. The values for the original and final densities are as follows :—

Percentage stretching.	Density.
0 (original wire)	7·695
3·6*	7·637

This shows a diminution of density of ½ per cent.

Effect of Drawing through Holes in a Steel Plate.

Copper Wire.—A length of the same copper wire as was used before, diameter 2 mm., was drawn, without any special care, through twenty holes of uniformly diminishing diameters, the density being measured after drawing through every third hole. Table I gives the results obtained. It will be seen that, whereas in stretching the density was diminished, in drawing it is considerably increased. There would seem to be a maximum after drawing through twelve holes, but as the wire became very difficult to draw by this time, and broke after being put through six more holes, the subsequent decrease in density may have been due to flaws in the metal, caused by the rough treatment which it had received. The ultimate diameter was 1·3 mm.

Table I.

	Density.
Before drawing........................	8·85
After drawing through three holes	8·87
,, ,, ,, more holes....	8·92
,, ,, ,, ,, ...	8·95
,, ,, ,, ,, ...	9·005
,, ,, ,, ,, ...	8·94
,, ,, ,, ,, ...	8·92

Manganese-Copper.—A length of this alloy (10 per cent. manganese, 90 per cent. copper), diameter 1·2 mm., was drawn through several holes, till the diameter was reduced to 0·6 mm., the results for the original and final densities being as follows :—

Density of original wire = 8·53
,, after being drawn = 8·615

Effect of Twisting.

A length of 130 cm. of 98 per cent. electrical conductivity wire, diameter 2 mm., was fixed at one end to a support, and a weight of

* Wire broke.

56 lbs. attached to the other end. While this weight was on, 300 complete turns were made in the wire, the density being measured after 200 turns, and again after 300 turns. It was found that the wire had stretched by about 23 per cent. after being thus treated. The density, as will be seen, increased very slightly—about $\frac{1}{2}$ per cent.

Density before twisting = 8·850
„ after 200 turns = 8·887
„ „ 300 „ = 8·896

A twist of 300 turns in a length of 130 cm. represents 2·3 turns per centimetre.

This wire was also tested for alteration of torsional rigidity and Young's modulus by Mr. J. E. Monroe, with the following results:—

Length of wire = 425 cm.

Number of twists.		Torsional rigidity, grammes per square centimetre.	Young's modulus, dynes per square centimetre.
Twists put in.	Permanent twists.		
0	0	$4 \cdot 07 \times 10^{11}$	$1 \cdot 116 \times 10^{12}$
5	0	$4 \cdot 07 \times 10^{11}$	$1 \cdot 152 \times 10^{12}$
10	—	$3 \cdot 994 \times 10^{11}$	$1 \cdot 17 \times 10^{12}$
15	—	$3 \cdot 947 \times 10^{11}$	$1 \cdot 152 \times 10^{12}$

Heating.

A preliminary trial was made on the effect of heating. The wire which had been used in the experiments just described was raised to a white heat by an electric current, to find out if by this means the density could be brought back to its original value which it had before being twisted. The heating, however, did not seem to alter the density appreciably, the difference not being more than $\frac{1}{10}$ or $\frac{1}{15}$ per cent.

Effect of Hammering.

A piece of copper wire was flattened by heavy blows with a hammer, and the density measured. The hammering was then continued, and the density again measured.

Density of original wire = 8·866
„ after first hammering = 8·868
„ „ second hammering = 8·875

Part II.

By James H. Gray and James B. Henderson.

Tests on Change of Electrical Resistance.

Several methods were tried with more or less success at the beginning of the work of Part I. Great difficulty was at first experienced with thermo-electric currents and the self-induction of some of the coils used. Ultimately, the zero method about to be described was perfected, and was used in the work of Part II, giving great satisfaction.

Before describing this method, we wish to refer particularly to the two definitions of specific resistance at present employed. The unit most generally understood in English treatises is the resistance in ohms of a cube of the metal of unit section and unit length. From this definition we have, for the resistance R, of a length l, of a homogeneous conductor of uniform section ω,

$$R = \sigma_v l/\omega,$$

where σ_v is the specific resistance so defined. σ_v may be called the "volume specific resistance," in contradistinction to the "weight specific resistance" σ_w, which is defined from the following. We have

$$R = \sigma_v \frac{l}{\omega} = \sigma_v \rho \frac{l^2}{l\omega\rho} = \sigma_w \frac{l}{w} l,$$

where $\sigma_v \rho = \sigma_w$, w being the weight of the length l of the wire. From this, σ_w is seen to be the resistance of a length of the wire numerically equal to ρ and section unity, or of a length unity and section equal to $1/\rho$. Since the section is uniform, l/w, or the length per unit of weight, is constant. Let it be represented by λ. Then we have

$$R = \sigma_w \lambda l.$$

The advantages of using this latter equation over the one involving the "volume specific resistance" are very many, either when it is required to know the whole resistance of a wire, having given σ_w, λ, and l, or when it is required to know σ_w, having given R, λ and l.

It is quite usual in commercial circles to speak of a wire of, say, number 14 gauge, weighing 127 grains to the foot, that is, about 27 grammes to the metre. The only measurement to be taken then is the length, if the specific resistance be given in weight units, and the measurement of the length can be made with the greatest accuracy. Even if the weight per unit of length be not given, it can also be determined most accurately without any difficulty.

If, however, the specific resistance be given in volume units, the

section of the wire must be measured, and this is a very difficult thing to do, even in the case of moderately thick wires, when accuracy is required, since an error in the measurement of the diameter is more than doubled in the value of the section. Everyone who has tried to measure accurately the diameters of wires is well aware of the great difficulty in doing so. Even although the one measurement were quite accurate, the diameter at the place measured would, in all probability, not be the average diameter of the wire. This can, of course, be corrected by taking measurements at a number of places, and taking the average, but the process is very tedious, and, when done, is not thoroughly trustworthy, for it is so easy to make errors in using the ordinary micrometer gauge. If the section be determined by the longer method from a measurement of the density, it is, of course, more accurately obtained, but, even then, the weighing in water of small lengths of wire is an uncertain thing; whereas, for the length per unit of weight, the weighing has only to be made in air, and therefore the error due to weighing in water is avoided. Clearly, then, the "weight specific resistance" gives much more accurate results for the total resistance of a wire than the "volume specific resistance," particularly in the case of practical work, where very little care is taken in measuring the diameter. Certainly, it would have been incomparably more difficult, and would have taken a much longer time to obtain the results given in this paper, had the "volume specific resistance" been used. As will be shown further on, it is not necessary, for mere comparison of two specific resistances, even to measure the length per unit of weight.

Dr. A. Matthiessen, F.R.S., in his paper "On the Specific Resistance of Metals in terms of the British Association Unit (1864) of Electric Resistance, &c." ('Phil. Mag.,' May, 1865), says:—

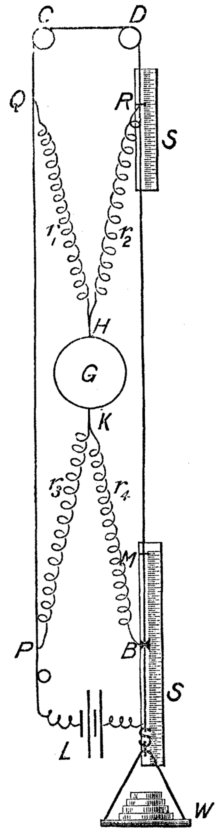
"We employed the length weight in preference to the length section, knowing that the weight of a wire may be much more accurately determined than its section, whether deduced directly from the measurements of the diameter, or indirectly from the specific gravity, the determination of the latter introducing an error. Of course, in endeavouring to reproduce resistances, it is wise to avoid the use of unnecessary values; and it is just as well, and certainly a much more accurate method, to determine a resistance in length weight than in length section."

The term "specific resistance" was introduced by Weber, but by it he meant the weight unit, and always used it unless when otherwise stated. Lord Kelvin points this out in his paper on "Measurement of Electromotive Forces in Absolute Measure" (vol. 1, 'Math. and Phys. Papers'), and throughout three papers relating to the present investigation, on "Electromagnetic Qualities of Metals," "Analytical

and Synthetical Attempts to ascertain the cause of the Differences of Electrical Conductivity discovered in Wires of nearly Pure Copper," and "On the Electric Conductivity of Commercial Copper of various kinds," printed in his collected papers, the "weight specific resistance" is always used. Several of the most eminent authorities have from time to time signified their disapproval of the volume unit, but it still continues to be most generally used. Why this is so does not seem clear, for surely a much more definite idea of a metal is obtained when its density is taken into account as in the weight unit; and if, for certain purposes, the volume unit may be convenient, this can easily be found from a knowledge of the density. It has been conclusively established, first by Lord Kelvin, and afterwards by several investigators, that the volume specific resistance always increases with the decrease of density, and therefore the weight resistance, since it includes the density, will not change so much. The weight unit is not, however, quite constant, as the results of this investigation show, but the changes, at least for copper, iron, and steel, are very small. As a matter of fact, for these metals the volume specific resistance does not change very much either, as the density is practically constant for any mechanical treatment.

The method used for the test of change of specific resistance was a slight modification of that known as Thomson's (Lord Kelvin) Double Bridge Method ("New Electrodynamic Balance for Resistance of Short Bars or Wires," 'Phil. Mag.,' 4th Series, vol. 24, 1862, p. 149). Diagram 2 is a sketch of the arrangements. A length of wire, PCDB, of about 10 metres, was fixed about its middle point round two strong bolts, C and D, which were fixed firmly near the ceiling in a pillar of the physical laboratory. At the points P, Q, R, the ends of 150 ohms resistances, r_1, r_2, r_3, were neatly soldered, the other ends of these resistances from Q and R being brought to one terminal, H, of a Thomson's mirror galvanometer G, of resistance 5380 ohms, the end of the resistance from P being connected to the other terminal K of the galvanometer. From K another 150 ohms resistance, r_4, was carried to a sliding contact, B. The four resistances of 150 ohms each were inserted so that practically all the current from the battery L would flow in the circuit PCDB, and thus any movement of B will not sensibly disturb the distribution in this circuit. As will be at once seen, if the resistance of the wire PQ is equal to that of BR, there will be no deflection in the galvanometer. The wire PQ was left unaltered, and served as a standard of comparison for BR, which was subjected to successive stretchings by means of weights, W. Half-millimetre scales, S, S, fixed immediately behind the points R and B, enabled the readings of length, BR, to be accurately taken.

DIAGRAM 2.



The order of an experiment was as follows:—The test wire BR was first of all made as straight as possible by means of a small weight. The sliding contact B was then moved about till there was no deflection in the galvanometer. Readings were taken at the points B, R, and also at a pointer, M, fixed on the wire near the top of the bottom scale S. A weight of 7 lbs. was then added to the small weight, and a balance again taken. The additional weight was then taken off, and a balance found. In this way, successive additions of 7 lbs. were made, and balance readings taken each time till the wire broke. The distance between the wires was about 10 cm., and the length between B and R from 400 to 450 cm. The galvanometer was made so sensitive that a movement of B of $\frac{1}{4}$ mm. could be distinctly detected, so that a change of $\frac{1}{4}$ in 4000, that is, 1/160 per cent. was measurable, and allowing for small errors in

reading the knife-edge of B, the result could be easily obtained correct to $\frac{1}{30}$ per cent. The method being a zero one, the galvanometer could be made almost unstable, and, as there are over 23,000 turns on the coil, the arrangement was exceedingly sensitive. The maximum current used was 0·5 ampère, and, in the case of iron and steel wire, not more than 0·25 ampère.

The four resistances r_1, r_2, r_3, and r_4, of 150 ohms each, were carefully wound anti-inductively side by side on a piece of slate, and covered with cotton tape, to ensure their being at the same temperature. The whole system of wires was so arranged as not to influence the galvanometer. The distance between the standard and test wire being so small, the temperatures of both were the same, and the sliding contact, at the point where it had to be touched by the hand, was protected by a piece of vulcanite from being heated. With these precautions, no inconvenience was experienced from thermo-electric currents.

Calculation of Results.

From the method of calculation it will be seen that it was only necessary to measure lengths in order to obtain results of the variations of the weight specific resistance, and to determine densities in addition, when the volume resistance was also required. The measurement of so great lengths as 400 cm. could be made very accurately, and, therefore, very little error was introduced. In no case was it necessary to measure the section in connexion with the resistance.

Let l = original length of the test wire which would give a balance with the standard, l' = the length which would give a balance after applying weight to it, L = the original length between R and M before applying weight, ω = the section before applying weight, L', ω' the corresponding values after applying weight,

σ_v = volume specific resistance,
σ_w = weight specific resistance,
R = resistance between the points P and Q on the standard.

Then, since the sliding contact on the test wire is always adjusted till the resistance is equal to R_1, we have

$$\begin{aligned} R &= \sigma_v \frac{l}{\omega} = \sigma'_v \frac{l'}{\omega'}, \\ &= \sigma_v \rho \frac{l}{\omega \rho} = \sigma'_v \rho' \frac{l'}{\omega' \rho'}, \end{aligned}$$

where ρ = density before applying weight,
ρ' = ,, after ,, ,,

But, since the weight of the length between the two fixed marks, R and M, on the wire, remains constant, we have—

$$\text{weight} = L\omega\rho = L'\omega'\rho' ;$$

$$\therefore \frac{\omega'\rho'}{\omega\rho} = \frac{L}{L'} ;$$

$$\therefore \frac{\sigma'_w}{\sigma_w} \equiv \frac{l'_v\rho'}{\sigma_v\rho} = \frac{l}{l'} \times \frac{\omega'\rho'}{\omega\rho} ;$$

$$\therefore \frac{\sigma'_w}{\sigma_w} = \frac{l}{l'} \times \frac{L}{L'} .$$

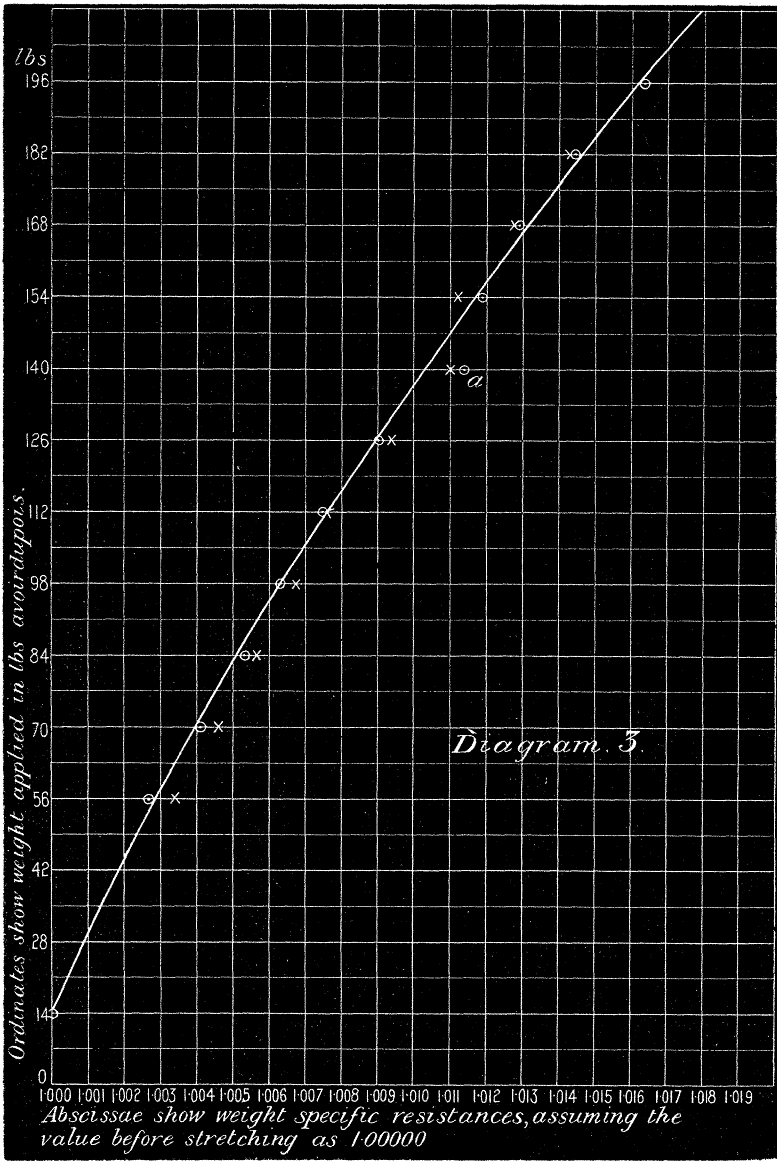
Thus, when a balance has been found, it is only necessary to measure, by means of the scales S_1 S, the lengths l' and L′, the other two, l and L, having been read before the weights were applied. The ratio of the weight resistances after and before stretching is thus obtained. If the ratio of the volume resistances is required, we have $\sigma'_w/\sigma_w = \sigma'_v\rho'/\sigma_v\rho$, so that, by cutting off suitable lengths of the wire and determining their densities, we get σ'_v/σ_v.

The preliminary trials of this method were made on copper wire with the help of Mr. Hamilton Wingate. The results obtained quite agreed with what Lord Kelvin first, and Mr. Tomlinson afterwards, found, that the mechanical treatment did not materially affect the specific resistance.

Tests of Steel Wire.

Pianoforte steel wire, of diameter 0·8 mm., was used, and straightened by a weight of 14 lbs. An additional 42 lbs. weight was

Column 1.	Column 2.	Column 3.	Column 4.
Weight applied in lbs. avoirdupois.	Ratio of weight specific resistance with weight on to weight specific resistance before applying any weight.	Ratio of weight specific resistance with weight on to weight specific resistance after the weight has been taken off.	Ratio of weight specific resistance after weight was taken off to that before any weight was appplied.
14	1·0000	1·0000	1·0000
56	1·0027	1·0034	0·9993
70	1·0041	1·0046	0·9994
84	1·0054	1·0056	0·9998
98	1·0064	1·0067	0·9997
112	1·0075	1·0076	0·9999
126	1·0091	1·0095	0·9996
140	1·0115	1·0110	1·0004
154	1·0119	1·0112	1·0006
168	1·0130	1·0129	1·0000
182	1·0145	1·0144	1·0001
196	1·0163	1·0165	0·9999



Curve of results given in Columns 2 and 3.

added, and a balance found. This was then taken off, and a balance again taken.

The calculations from these readings give the temporary altera-

tion of specific resistance due to the strain caused by the weight, and the permanent alteration due to the weight having been applied for about ten minutes, and then taken off. This series was continued by making successive additions of 14 lbs. till the wire broke, which it did when a little more than 200 lbs. had been added. The results obtained for one of four series are given in the table, p. 293. This series was chosen because more intermediate readings had been taken than in the other three. All four agreed at the common points within the limits of accuracy of the method.

The headings of the columns sufficiently explain what the numbers mean. Column 4 shows that application of weight up to 84 lbs. had the effect of slightly improving the permanent electrical quality of the steel. When more than 84 lbs. were applied the conductivity was found to diminish again. The results in column 2 are shown plotted on the curves in Diagram 3. Columns 2 and 3 are almost identical, as shown by column 4, which is the ratio of the two. The numbers in column 4 are, within the accuracy of the method, practically unity, showing that there has been no permanent alteration of specific resistance. With regard to the points *a*, *a* in each curve, which are out to the amount of 5 in 10,000, it must be remarked that these were the beginning of the second day's experiments. It was impossible to carry out a whole series of tests in one day, and, therefore, the wire was left over night with a weight of 14 lbs. on it.

The temporary alteration of specific resistance in the case of steel is considerably higher than the temporary or permanent alteration for copper or iron, as will be seen from the results given for these metals.

Tests of Copper Wire.

A very large number of tests were made on the effect of stretching on the specific resistance of copper wire. The wire was the same material as that used for tests of density, but of slightly smaller diameter. The following table gives the results of one set:—

(1.) Percentage stretching.	(2.) Ratio of weight specific resistance after weight was taken off to that before any weight was applied.
0·0000	1·00000
0·05	0·99969
0·5	0·99985
2·5	1·00104
6·5	1·00415
12·5	1·00666
16·2	1·00682
22·3	1·01083 (abnormal)

In this table the percentage stretchings are given instead of the weights producing the stretching, as, copper being so soft, the effect of the weights depends altogether on the times during which they were applied, and as these were very variable, a record of the weights would be of no value. For example, if a weight were put on, and allowed to hang for three minutes, then taken off, and a balance immediately found, and if the same weight be again put on, left for another three minutes, and a balance again found, it would be considerably different from before, showing that the wire had received an additional stretching. For this reason it is advisable to give the percentage stretching produced. In the case of steel wire it was quite different, as, throughout all the series, till the wire was just about to break, the elastic limit was not exceeded, so that the wire attained its ultimate stretching as soon as the weight was applied. With regard to this table, the results given are one set out of a great many which agreed very closely, $\frac{1}{10}$ per cent. being the greatest variations for corresponding stretchings; this set was chosen as having one peculiarity very well marked. This is with reference to the high value 1·01083, that is, an increase of 1 per cent. for a stretching of 22·3 per cent. The wire was almost at breaking point, and, on being examined, the surface was found to contain numerous cracks, many of which were so large that they could be easily felt by the fingers. These cracks were no doubt caused by the rapidity of stretching, as in other series in which the stretching was conducted more slowly they were not so apparent, and the change of specific resistance was not so great.

It was found quite impossible to smoothe out all the little deviations from perfect straightness in the copper wire. Although the first 14 lbs. were sufficient to keep it fairly straight, there were still little irregularities which could be seen with the eye. Not till about 56 lbs. were applied were these quite removed, and by that time there was also considerable stretching. The result was to make the apparent initial length shorter than it really was, and therefore the specific resistance seemed to diminish at first with the addition of weight. After the irregularities were taken out by stretching the length appeared to become greater, while the resistance did not increase, the result being that the specific resistance would seem to have diminished. This showed itself to a greater or less degree in all the series, according to the condition of the wire as to straightness. The values 0·99969, 0·99985 are clearly due to this. It might, therefore, have been more accurate to give the results, taking as the initial reading the lengths after the irregularities had been removed; but this would only very slightly alter the values, in fact by $\frac{1}{30}$ per cent.

Leaving out the value of the alteration just before breaking, we find in all our trials that the greatest increase of weight specific

resistance is not more than 0·7 per cent. This corroborates, for copper, very well what Lord Kelvin found in his first experiments on this subject. Since the density of the wire diminishes by 0·3 per cent., the increase of volume specific resistance is about 0·9 per cent., a result somewhat higher than Mr. Tomlinson's for the copper which he used, as he got 0·6 per cent. for the maximum value. We assume that the latter investigator means "volume specific resistance" by the term "specific resistance"; otherwise our results would agree more nearly with his. In any case, it seems quite certain that, in copper, the greatest alteration that can be produced by any mechanical treatment is not more than would be produced by a rise of temperature of 3° Centigrade.

For additional tests of copper, see end of paper.

Tests of Soft Iron Wire.

The wire, 0·8 mm. here used was exceedingly soft, and gave very satisfactory results. This metal is intermediate in properties between copper and steel. Whereas in copper the permanent alteration and stretching begin almost simultaneously with the application of weight, and in steel the alteration is almost altogether temporary, that is, only lasts while the weight is on the wire, in soft iron wire there is both a temporary and permanent alteration.

The same length of wire was taken as for copper and steel, and weights added by 7 lbs. each time, tests being made after each addition. A comparison was made of the ratio of the weight specific resistance with weight on to that before any weight was applied. This gives column 3 in the following table, and shows the ratio due to the sum of the temporary and permanent alterations.

Column 1.	Column 2.	Column 3.	Column 4.	Column 5.
Weight in lbs.	Percentage stretching.	Ratio of weight specific resistance with weight on to that before any weight was applied.	Ratio of weight specific resistance with weight on to that after the weight had been taken off.	Ratio of weight specific resistance after weight was taken off to that before any weight was applied.
14	0·00	1·00000	1·00000	1·00000
21	0·155	1·00056	1·00026	1·00030
28	0·21	1·00072	1·00103	0·99964
35	1·7	1·00128	1·00154	0·99969
42	4·0	1·00179	1·00160	1·00018
49	8·0	1·00424	1·00224	1·00192
56	15·5	no test	no test	1·00186

A comparison was also made of the ratio of the weight specific resistance while the weight was on with that immediately after the weight was taken off. The results are given in column 4 of the table. Column 5, which is obtained by dividing the results of column 3 by the corresponding numbers in column 4, gives therefore the permanent alteration due to stretching. In this table both the weights and the percentage stretchings are given, as it was found that with iron the difficulty experienced with copper of continuous stretching did not occur.

In order to test if there was any more permanent stretching after the wire had been allowed to rest for a week, another series of tests was made on the same wire at the end of the week, readings being taken on the application of every 7 lbs. as before. The results showed that the temporary alteration remained the same as before, being for 49 lbs. 1·002234, which, as will be seen by subtracting column 4 from column 2 to get the temporary alteration, the result being for 49 lbs. 1·00232, shows that the permanent alteration is practically constant after the first series of stretchings.

No tests have been made of alloys as yet, as it was thought more important to give as much time as possible to obtaining trustworthy results for pure metals.

The conclusions that have been arrived at from this investigation are that no mechanical treatment, such as stretching, drawing through holes in a steel plate, twisting, hammering, or combinations of these, all of which were tried, had any appreciable effect on the electrical properties of copper, iron, or steel.

The effect of annealing was also tried on a copper wire which had already been very much stretched. The wire was carefully heated to redness by means of a lamp all along its length, and a test then made. This was not found to bring its resistance back to its original value however.

As contrasted with the small effect that mechanical treatment has on the electrical properties of metals, it is interesting to notice the great influence even a trace of impurity in the metal has. For this purpose we include a table taken from Lord Kelvin's paper on "Analytical and Synthetical Attempts to ascertain the cause of the Differences of Electrical Conductivity discovered in Wires of nearly Pure Copper" (vol. 2, 'Math. and Phys. Papers'). This table (p. 299) gives an analysis, made by Professor Hofmann for Lord Kelvin, of several specimens of copper, and also their conducting powers.

From this table we see that an impurity of $\frac{1}{3}$ per cent. lowers the conducting power by as much as $5\frac{1}{2}$ per cent., and that the conducting power rapidly becomes enormously lower for increase in the impurities, 1·24 per cent. of the latter bringing down by 40 per cent. of its value when pure.

Conductivity of the wire in relative measure.	Qualitative analysis.	Percentage of copper.	Amount of impurities.
42·0	Copper, iron, nickel, arsenic, oxygen	98·76	1·24
71·3	Copper, iron, nickel, oxygen	99·20	0·8
84·7	Copper, iron, nickel (doubtful), oxygen	99·53	0·47
86·4	Copper, iron, nickel (doubtful), oxygen	99·57	0·43
102·0	Copper, iron, oxygen	99·9	0·10

Renewed Test on Copper Wire made after the Paper was written.

This series was made in order to find if, after the wire had been stretched almost to breaking and allowed to stand, there would be any more permanent alteration of specific resistance due to renewed application of weight. First of all, a series of stretchings was given to the wire, as in the former tests of the same wire. Column 2 of the following Table A was thus obtained, and will be found to agree very well with column 2 given under "Tests of Copper Wire" in the former series.

This wire was then tested by applying successive weights, the readings being taken with weight on and also after the weight had been taken off. Columns (2) and (3) of Table B give the results of these tests. Column (2) shows the ratio of the weight specific resistance with the weight on to that before the weights were applied for the second series. Column (3) gives the ratio with weight off to that before the weights were applied. Column (2) therefore shows the permanent and temporary alteration, and (3) shows the permanent alteration. There was, however, still a slight permanent stretching, which accounts for the small increases shown in Column (3). The results showed that when there was no permanent stretching application of weight only caused temporary alteration of weight specific resistance.

The numbers in columns (2) of Tables A and B when plotted on curved paper, with (for A) percentage stretchings as ordinates, and weight specific resistances as abscissæ, and (for B) weights applied as ordinates, give practically straight lines. This shows that the permanent alteration of specific resistance is directly proportional to the stretching, and the temporary alteration is directly proportional to the weight applied.

Table A.

(1.) Percentage stretching.	(2.) Ratio of weight specific resistance after stretching to that before stretching.
0·04	1·000000
0·04	1·000037
1·82	1·000711
4·7	1·002463
9·06	1·003776
16·63	1·007128
21·98	1·010363

Table B.

(1.) Weight applied in lbs. avoirdupois.	(2.) Ratio of weight specific resistance with weight *on* to that before applying weight.	(3.) Ratio of weight specific resistance with weight *off* to that before applying weight.
14	1·00000	1·00000
28	1·00487	1·00000
56	1·00131	1·00000
70	1·00185	1·00005
84	1·00237	1·00010
98	1·00283	1·00090

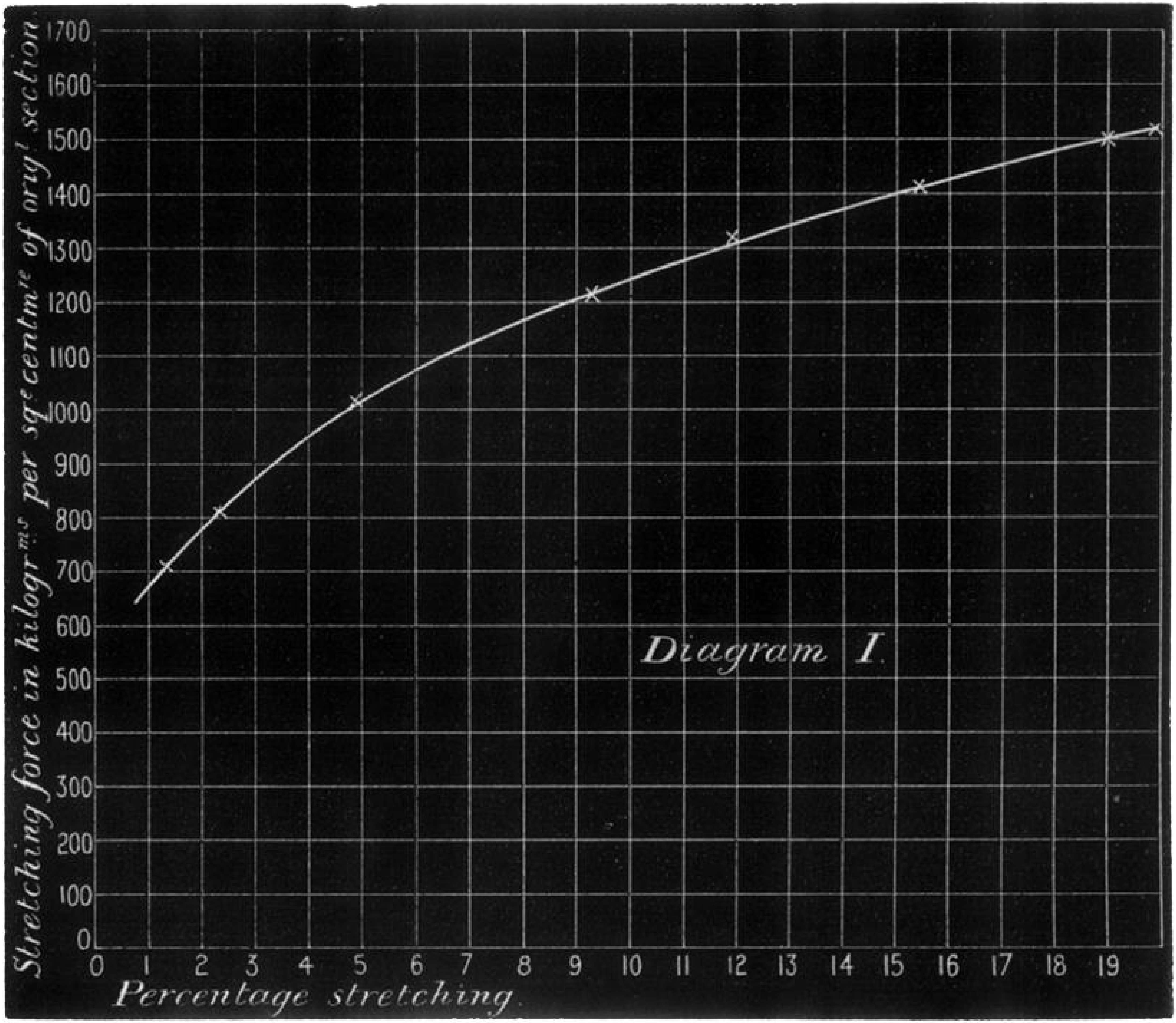
"The Action of Gravity upon *Bacterium Zopfii*." By Rubert Boyce, M.B., M.R.C.S., Assistant Professor of Pathology, University College, London, and A. Ernest Evans, M.B., C.M., Glasgow. Communicated by Professor Victor Horsley, F.R.S. Received February 7,—Read February 23, 1893.*

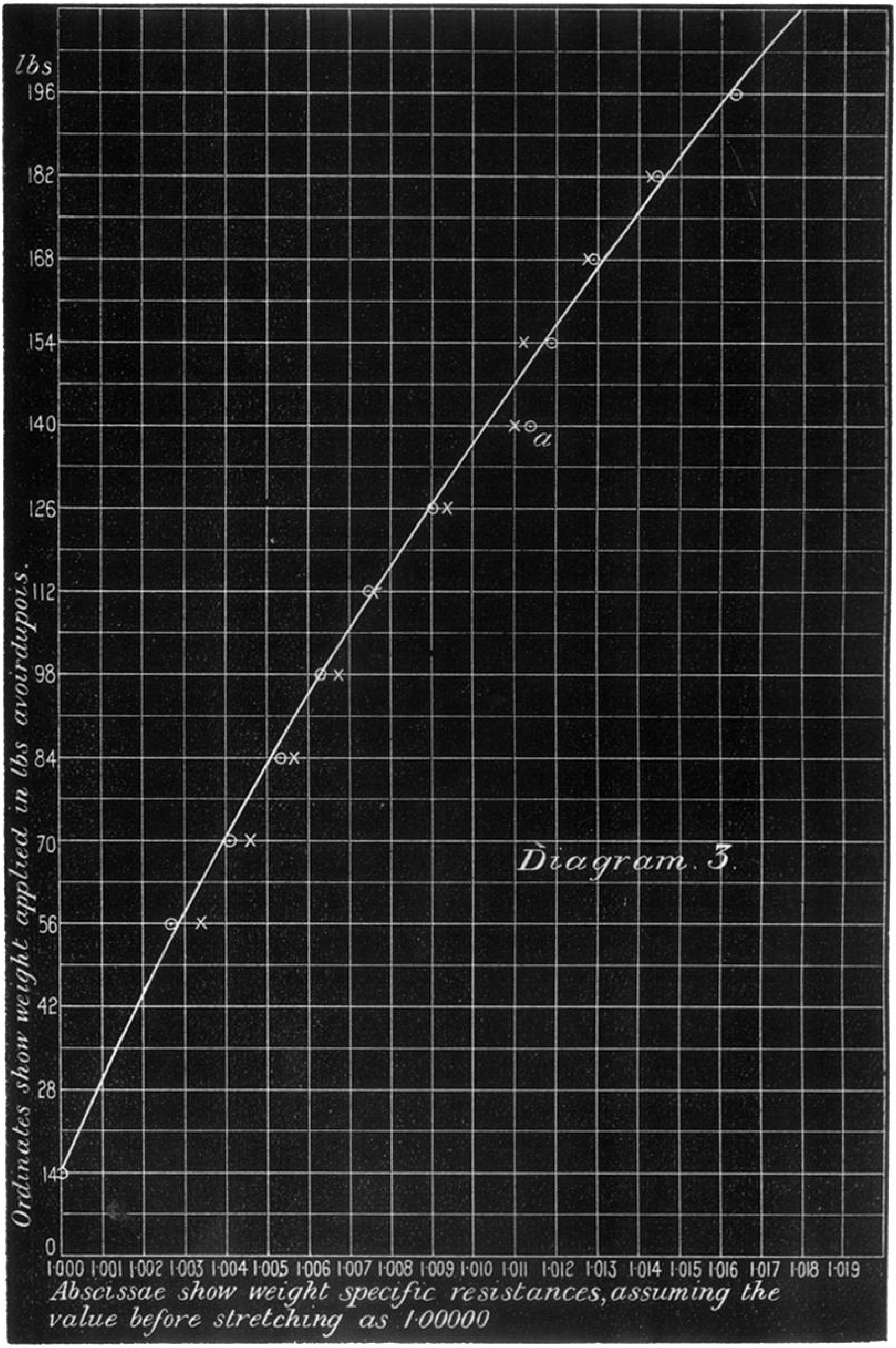
(From the Pathological Laboratory of University College, London.)

[Plates 1 and 2.]

In May, 1892, Mr. Walter Spencer handed over to us the body of a cat in which he had discovered a double otitis media. Some of the pus was immediately inoculated upon gelatine, and two days later it was seen that the gelatine along the streak had liquefied, whilst the rest of the surface of the non-liquefied gelatine was covered by a

* Of the numerous photographs illustrating this paper, only five of the more typical ones are reproduced, namely, figs. 10, 12, 14, 23, 28. It has been thought better, however, to preserve the original numeration in the text, as the original photographs can be consulted if necessary.


Stretching force in kilogr.ms per sq.e centm.e of orig.l section
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Percentage stretching.
Diagram I.



Curve of results given in Columns 2 and 3.